

Galaxy Dynamics: from the Early Universe to the Present
ASP Conference Series, Vol. 3 × 10⁸, 1999
F. Combes, G. A. Mamon and V. Charmandaris, eds.

Centers of Barred Galaxies: Secondary Bars and Gas Flows

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1. Introduction

Active Galactic Nuclei (AGN) require mass accretion onto the central engine. On large galactic scales, torques from a stellar bar can efficiently remove angular momentum from gas, and cause it to move inwards along two hydrodynamical shocks on the leading edges of the bar. Inflowing gas settles on near-circular orbits around the Inner Lindblad Resonance (ILR), and forms a nuclear ring, about 1 kpc in size. A secondary bar inside the main one, with its own pair of shocks, has been proposed to drive further inflow, and thus feed the AGN in a manner similar to the inflow on large scales. Here, we report results of high resolution hydrodynamical simulations, where we examine the nature of the nuclear ring, and check how efficient double bars can be in fueling AGNs.

2. Hydrodynamical models with a single bar

All calculations have been done with a grid-based PPM code in 2 dimensions, for isothermal, non-selfgravitating gas, and point symmetry has been imposed. Excellent resolution near the galaxy center (better than 20 pc inside the nuclear ring) was achieved by using a polar grid. In order to trace shocks better, we calculated the value $\text{div}^2 \mathbf{v}$ throughout the grid, where $\text{div} \mathbf{v} < 0$, and displayed it next to the density diagrams.

The nuclear ring at low gas sound speeds ($c_s = 5 \text{ km s}^{-1}$) is made of a tightly wound spiral (Piner, Stone & Teuben 1995 ApJ 449, 508) with no shocks (Fig.1 *left*). The pair of straight main shocks in the bar ends clearly at the outer edge of the nuclear ring, and only a weak, tightly wound sound wave propagates through gas inside the ring. There is no significant gas inflow to the center.

The exceptionally high resolution of our method allowed us to study the structure of the gas flow at high sound speed (20 km s^{-1}). Instead of the nuclear ring, a nuclear spiral with higher pitch angle develops (Fig.1 *center*). Its presence on the $\text{div}^2 \mathbf{v}$ plot indicates a spiraling shock, along which the gas falls towards the center. We predict a significant gas inflow here, which can fuel an AGN.

3. Results for a dynamically possible double bar

In a dynamically possible double bar, the primary bar must have an ILR, and the secondary bar must end well within the outer ILR of the main bar (Maciejewski & Sparke 1999 MNRAS *in print*). Resonant coupling favors the existence of stable orbits supporting double bars (Tagger *et al.* 1987 ApJ 318, L43). Coupling

the corotation resonance of the secondary bar with the outer ILR of the main bar causes the dynamically possible secondary bar to end well inside its own corotation, *i.e.* it rotates slowly.

A snapshot of gas flow in a dynamically possible system with two independently rotating bars (Fig.1 *right*) shows the nuclear ring widened or destroyed by the secondary bar. An elliptical ring develops around the inner bar, with a size that is largely independent of the sound speed: the flow is mainly elliptical with weak transient shocks. Straight shocks form in fast rotating bars only — they curl around a slow bar and turn into a ring (Athanasoula 1992, MNRAS 259, 345). No significant gas inflow to the center is seen, even at high sound speed.

4. Conclusions

In a singly barred galaxy both near-circular motion of gas in the nuclear ring, and a spiraling shock extending towards the galaxy center are possible, depending on the sound speed in the gas. A dynamically possible doubly barred galaxy is likely to have a slowly rotating secondary bar, which neither creates shocks in the gas flow, nor enhances gas inflow to the galaxy center.

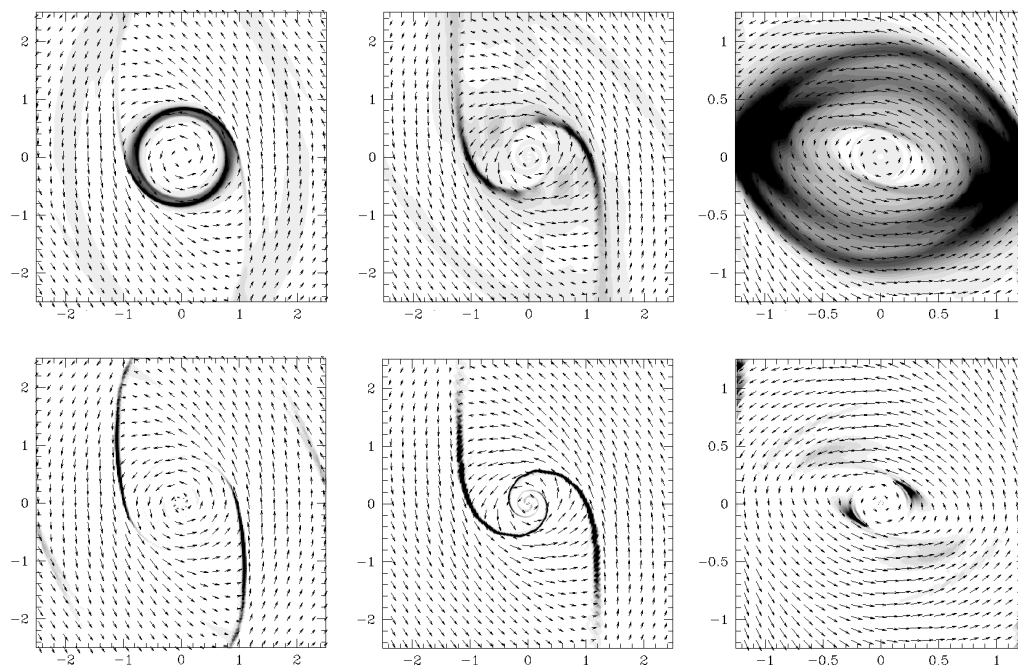


Figure 1. Density (*top*) and $\text{div}^2 \mathbf{v}$ (*bottom*) diagrams for inner regions of modeled gas flow in barred galaxies with ILRs. The velocity field is shown in the frame rotating with the main bar, which is vertical on all frames, rotates counterclockwise, with corotation resonance at 5.8, and outer ILR at 2.3 (units are in kpc). *Left*: flow in a single bar at $c_s = 5 \text{ km s}^{-1}$. *Center*: same for $c_s = 20 \text{ km s}^{-1}$. *Right*: flow in a double bar at $c_s = 5 \text{ km s}^{-1}$; the angle between the bars is 78° .